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The Design of Mine Dewatering Systems in Poland

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INTRODUCTION

Poland belongs to the group of countries that has relatively rich deposits of useful minerals. So mining and minerals processing are among the most developed branches of the national economy.

Because of the geological character of the ore deposits, and especially their various depths, both underground mining and surface mining are widely developed. (Figure No. 1)

Bituminous coal and copper, lead, and zinc ores are primarily extracted from underground mines. In total, underground production of all minerals reaches 250,000,000 tons per year. Of this total about 200,000,000 tons is bituminous coal. Underground mining is expected to increase by about 50 percent in the next 15 years.

Lignite, sulphur, stowing sands, and various clays as well as stones and aggregates for many purposes are extracted from surface mines. The total amount of useful minerals mined by surface methods is about 500,000,000 tons per year, and this requires removal of more than 200,000,000 cubic meters of overburden. In these totals lignite, with production of 40,000,000 tons per year and removal of 130,000,000 tons of overburden, is number one. Although the total

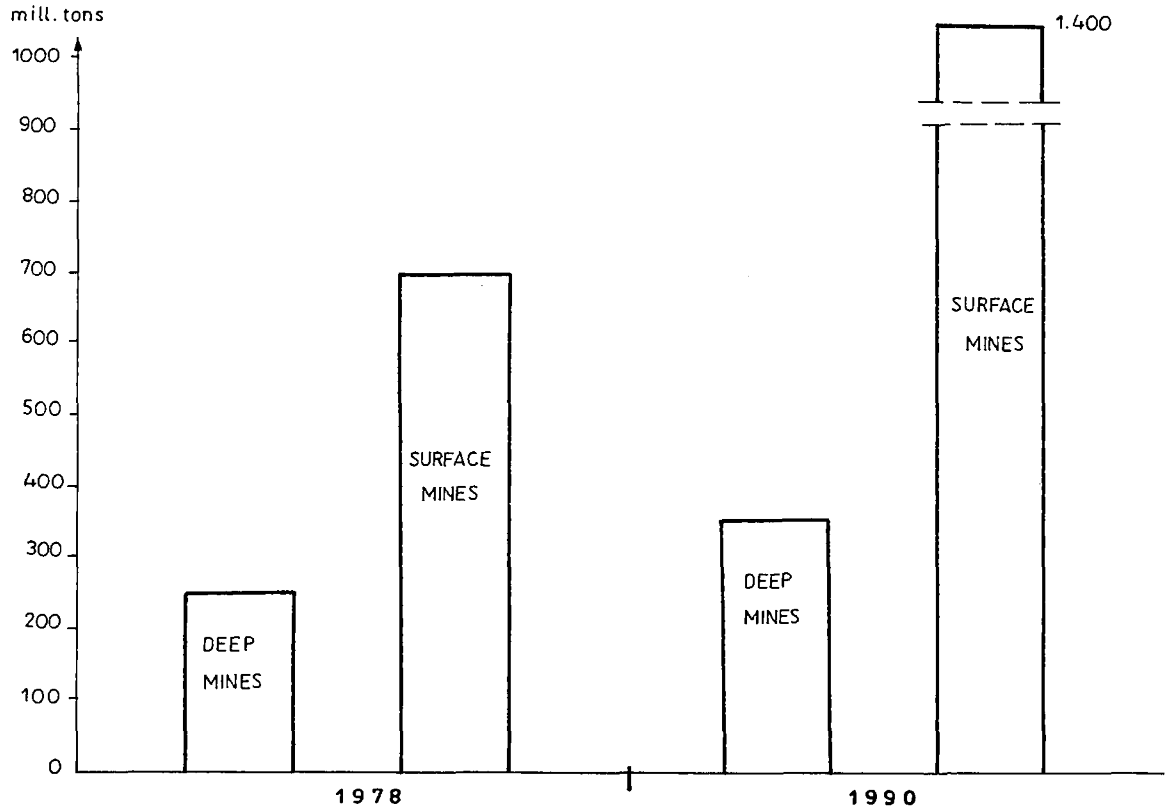


Fig.1. AMOUNTS OF MINERALS MINED IN POLAND

production of sands, gravels, and stones for constructions is greater, production is from so many small and shallow local operations that it is less important. In addition, with the fast development of lignite surface mining, annual production is expected to reach 80,000,000 tons in 1985 and about 140,000,000 tons in 1990-1995. This will require removal of 300,000,000 cubic meters of overburden per year and 700,000,000 cubic meters per year of overburden, respectively. Also the depth of surface mining operations will have increased to 300 meters during that time.

Such large mining operations are almost always conducted in water saturated strata--everywhere in Poland the groundwater table is just below ground level--make the dewatering of mines one of the principal challenges in mining operation design. Especially in surface mining, where the mined seam as well as the whole overburden has to be drained in advance of mining operations, the problem of dewatering is a major factor.

GEOLOGICAL AND HYDROLOGICAL CHARACTERISTICS OF POLISH MINES

To understand the mine dewatering systems, it is necessary to know the natural conditions and structure of deposits being mined.

In underground mines, the strata that determine the hydrologic situation in the mine are the seams and the footwall and hanging wall beds. This is because only these layers are cut by the mining operations; less important are the beds laying above. In surface mines, however, the whole overburden section is cut through, and all formations play a similar role in water conditions of a mine.

Underground Mines

Bituminous Coal. Poland's bituminous coal is mined (1) from the Carboniferous formation at the depth of 300 to 800 meters below ground level. (Figure No. 2) This formation is constituted of sandstones and shales (with coal seams) of a total thickness of several hundred meters. Carboniferous beds (Figure No. 2) are covered by the Triassic, Tertiary, and Quaternary formations, but sometimes directly by Quaternary Age sands. The amount of water inflow to mines is dependent on the amount and intensity of fractures occurring in the hanging wall formations and also on the character of rocks overlaying the Carboniferous series. The permeability

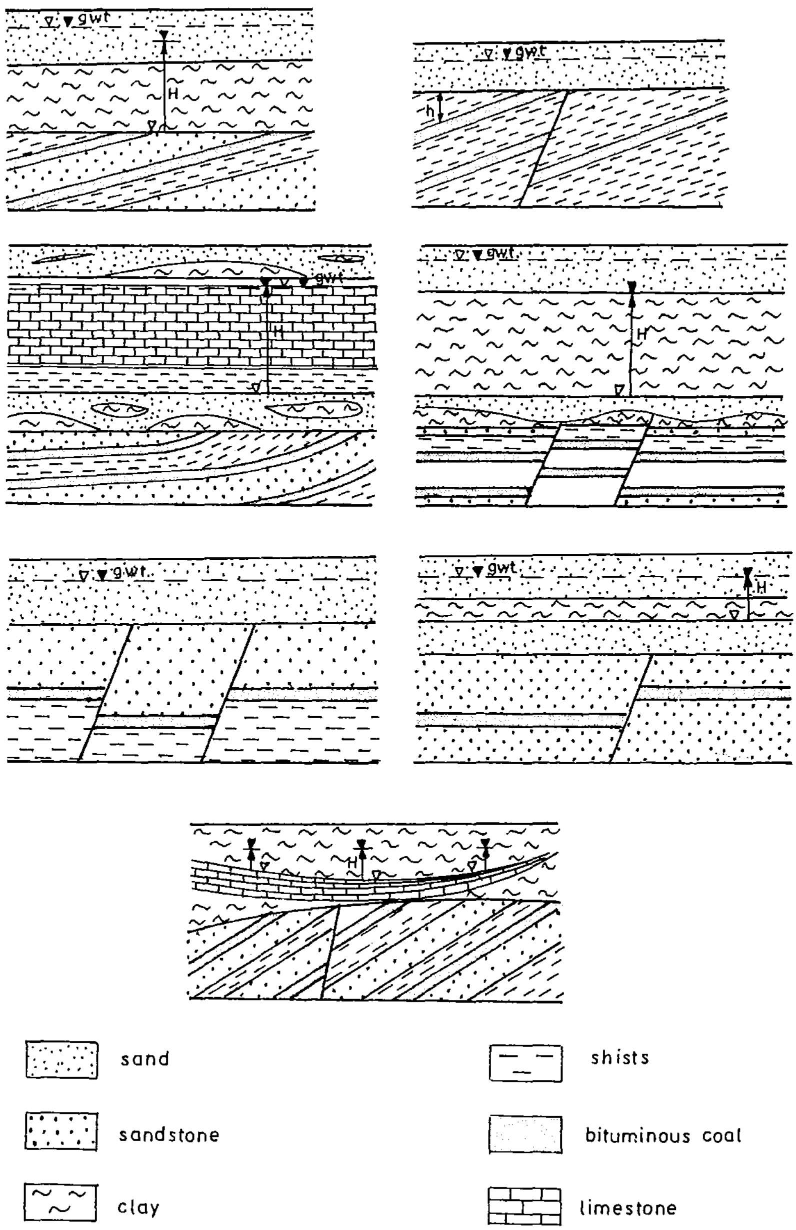


Fig. 2. TYPICAL HYDROGEOLOGICAL SECTIONS OF BITUMINOUS COAL DEPOSITS MINED BY UNDERGROUND MINES.

coefficient of Carboniferous sandstones is in the 0.005 to 1.0 meter per 24 hours range, and water inflows are between 1 cubic meter per minute (minimum) and 25 cubic meters per minute (maximum) in any mine.

Copper Ores. The copper ores occur in Poland in the Permian limestones and dolomites (1), which are overlain by Triassic sandstones and Tertiary formations represented by sands, clays, and lignite seams. The Quaternary series have been deposited on the top. The ore bearing limestones and dolomites--from which at the depth of 700 to 1,000 meters below ground level the ore is mined--have coefficient of permeabilit of 0.03 to 0.85 meter per 24 hours. Their permeability depen on how much the junctions and cavities have been filled with secondary material. The inflow of water to particular mines is 3 to 20 cubic meters per minute, and it is mostly a result of the character of rocks overlaying the limestone-dolomite series.

Zinc and Lead Ores. These ores are found in Poland in dolomi and limestone formations of the Triassic Age (Figure No. 3), which constitute the gentle synclinal forms. This formation is a very saturated aquifer due to fractures and cavities of karstic origin. The permeability coefficient of these strata is 1 to 24 meters per 24 hours. This aquifer is fed with water percolating from Quaternary sands of river valleys. Th inflow of water to the 150-meter deep underground mines is between 20 and 100 cubic meters per minute. The local inrush of water sometimes reaches 50 cubic meters per minute from one face.

Surface Mines

The hydrogeological conditions in surface mines are very important and their detailed investigation is required for proper operations design. This knowledge is of equal importance for the mined beds, the overburden, and the underlaying beds.

Lignite. All deposits of lignite in Poland are of the Tertia Age and could be roughly divided into three hydrogeological groups (Figure No. 4):

First group--one flat lignite seam (impermeable), 6 to 15 meters thick, covered by 25 to 75 meters of overburden, of which 70 to 80 percent are Tertiary and Quaternary clays and 20 to 30 percent are sands of the same age (in the form of

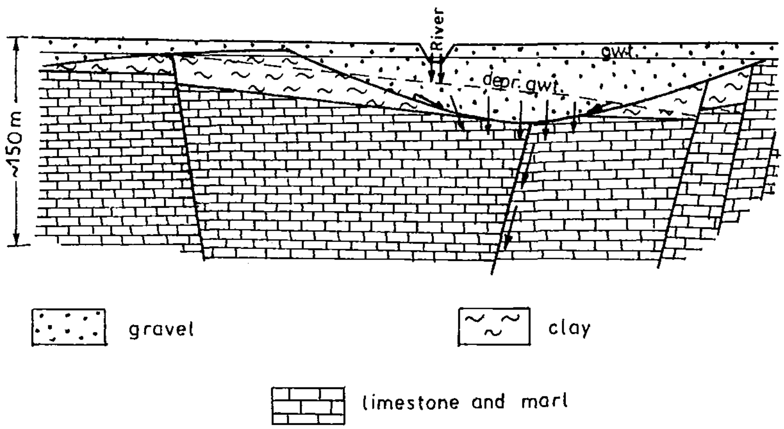


Fig. 3. HYDROGEOLOGICAL SECTION OF LEAD AND ZINC DEPOSITS MINED BY UNDERGROUND MINES.

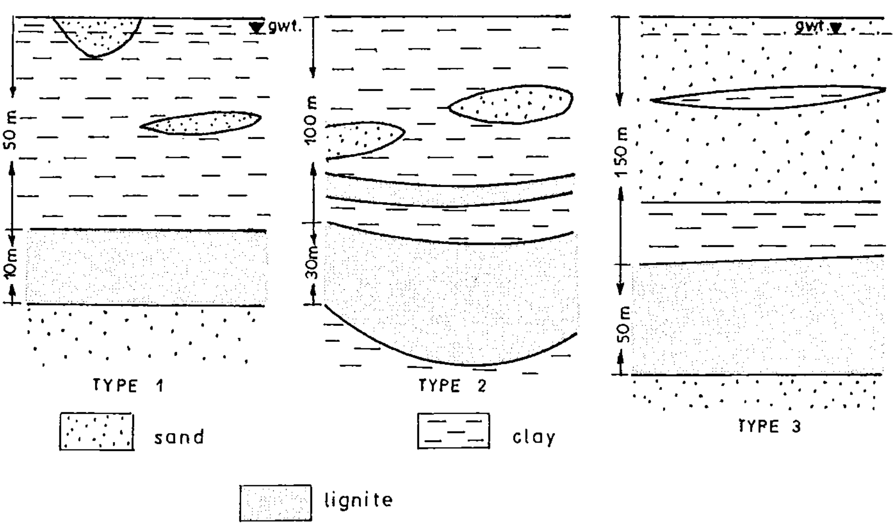


Fig.4. TYPICAL HYDROGEOLOGICAL SECTION OF LIGNITE DEPOSITS MINED BY SURFACE MINES.

closed lenses or erosion troughs). The lignite seam is underlain by saturated sands, 20 meters to 50 meters thick, containing subartesian water under pressure of 3 to 8 bars, and characterized by the permeability coefficient of 3 to 5 meters per 24 hours. The groundwater inflow to these mines is 30 to 100 cubic meters per minute.

Second group--multiseam basins in which overburden, the underlaying beds, and the intercalations consist of clays (70 to 80 percent) and of sands (20 to 30 percent) in the form of closed lenses. The sands' lenses contain static groundwater under pressure depending on the depth. Thickness of lignite seams is 5 to 40 meters, the depth of mining reaches 160 meters; groundwater inflow to these mines is 30 to 40 cubic meters per minute.

Third group--one or two lignite seams, 20 to 70 meters thick, are covered with sandy overburden, 100 to 200 meters thick and underlain with fine sands. Where lignite is deposited in tectonic trenches, the seams adjoin highly permeable limestones of Jurassic Age. The coefficient of permeability of overburden is 8 to 20 meters per 24 hours; of Jurassic limestones about 10 meters per 24 hours; and of Tertiary fine sands 1 to 3 meters per 24 hours. The natural groundwater table is just below ground level and so the hydrostatic pressure reached 30 bars; the inflow of groundwater to these mines, when drawdown reaches 300 meters depth, is about 400 cubic meters per minute.

Sulphur. The sulphur deposit is found (1) in the Miocene limestone beds (Figure No. 5). The upper part of overburden consists of the saturated Quaternary sands, 5 to 20 meters thick, being in contact with the large river Vistula; the lower part consists of the Tertiary clays, 50 to 70 meters thick. The sulphur occurs in fractured and saturated limestones characterized by coefficient of permeability of 40 meters per 24 hours. The limestones are underlain by fine sand (permeability coefficient 3 to 4 meters per 24 hours), 20 to 70 meters thick, where groundwater is under pressure of 3 to 8 bars. The inflow of groundwater to the mine is about 30 cubic meters per minute and TDS of these waters is in the 5 grams per cubic decimeter range.

Stowing Sands. As stowing sand--for backfilling of underground mine openings under cities--the Quaternary sands with a grain size of 0.25 to 0.50 millimeter are used. The deposits of these sands are always connected with river valleys (Figure No. 6). Thickness of these deposits (and the depth of mining

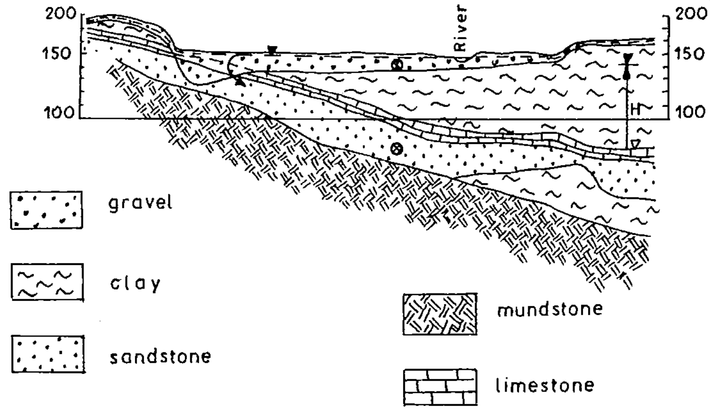


Fig. 5. HYDROGEOLOGICAL SECTION OF SULPHUR DEPOSITS MINED BY SURFACE MINES.

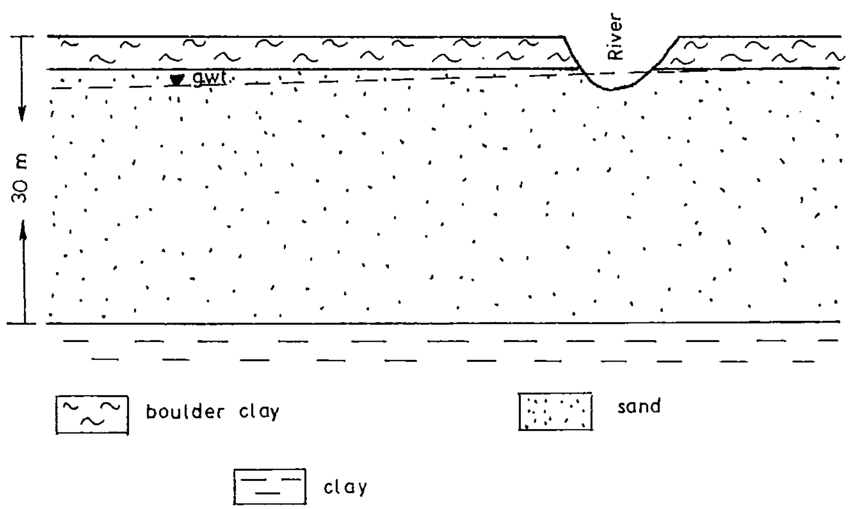


Fig. 6. HYDROGEOLOGICAL SECTION OF STOWING SAND DEPOSITS MINED BY SURFACE MINES.

operations) is 20 to 40 meters, and the sands are covered with thin topsoil only. Permeability coefficient of sands is 15 to 25 meters per 24 hours and the free groundwater table should be lowered 15 to 30 meters for mining operations. The groundwater inflows to these surface operations are 20 to 60 cubic meters per minute.

Clays. Clays mined for various ceramic and industrial purposes are found most often in small deposits of Tertiary or Quaternary Age. The thickness of overburden is almost always within 3 meters and the depth of operations does not exceed 30 meters. Groundwater occurs in small closed lenses of sand, and the inflow to particular mines does not exceed 1 to 2 cubic meters per minute.

Rocks and Aggregates. These operations (generally small) are conducted mostly in unsaturated beds. In the quarries, where operations are being conducted below groundwater table, the inflow of water coming from fractures does not exceed 3 cubic meters per minute. The gravel pits below the groundwater table are operated with dredging equipment.

MINING OPERATION SYSTEMS

To better understand the design of mine dewatering systems, it is necessary to know the extraction methods used. These, together with hydrogeological conditions, influence the design of mine dewatering systems.

Underground Mines

The production level of the main workings is generally accessible by vertical shafts that are 100 to 1,000 meters deep and 4.0 to 8.5 meters in diameter. Shaft sinking in soft ground is mostly done by hand, with blasting in hard rocks. The casing is installed simultaneously or in sections. In saturated beds the drawdown of groundwater by wells equipped with submersible pumps or a solidification or freezing is used. Close to the shaft bottom, chambers (among them the chamber for the pumping station) and water reservoirs (galleries) are driven. When ready, the galleries for the first mining are driven with the use of blasting and mechanical loading equipment. These headings are the most hazardous in difficult hydrogeological conditions.

Various methods of extraction are used in bituminous coal mining depending on:

- Depth of operations.
- Thickness of the coal seam to be mined.
- Roof and floor conditions.
- Inclination of coal seam.
- Minability of coal.
- Gas occurrences.

The seams up to 3 meters thick, flat or with small inclination, are mined with 200- to 250-meter longwalls and roof caving, when there are no special requirements to protect the land surface. Where a seam is dipping more than 30°, the "step by step" method with a dry backfilling is employed; the operation progresses from lower to upper levels.

The thick seams (above 3 meters), flat or gently inclined, formerly were mined by the room and pillar method. Recently the longwall method has been used. The seam is mined in 3.5-meter thick benches, using hydraulic backfilling or caving with an artificial roof; the operation progresses from the upper to lower benches. The steep and thick seams are always mined with the use of hydraulic backfilling.

In underground copper, zinc, and lead mines, the room and pillar method, with various modifications, is used. Blasting and caving are generally employed; backfilling is occasionally required to protect sensitive buildings on the surface above from subsidence.

Surface Mines

Lignite, sulphur, stowing sands and clays, as well as overburden of these deposits, are loose soils. So these useful minerals and the overburden are mined with bucket-wheel and bucket-chain excavators. The material is directly loaded on belt conveyors or sometimes on railway cars. Blasting is rarely necessary in these deposits; but, in quarry operations, blasting, shovels, draglines, and loaders and trucks for haulage are widely in use.

The stowing sands, clays, and rock deposits are covered with only a thin topsoil overburden. In these mines the extraction of the useful mineral begins right after removal of the topsoil (which is stored for further reclamation). However, in lignite surface mines (and also in the sulphur mine), where overburden is 30 to 130 meters thick, the large operations to make the "opening cut" (to uncover the lignite seam) have to be executed. The volume of overburden (clays and sands) to be removed, and transported outside the mine, in these operations ranges from 30,000,000 to 120,000,000 cubic meters. This requires two to four years. When the lignite seam is uncovered, simultaneous lignite mining and overburden removal begins. And when mining faces extend a fair distance, the backfilling of waste into the open pit can start. This operation--consisting of several overburden working levels and one to three working levels in lignite--moves through the deposit in a parallel or fan-shaped system. The output of one open pit, working as above, is 2,000,000 to 20,000,000 tons per year of lignite and 10,000,000 to 50,000,000 cubic meters per year of waste. During the next two years, a mine with an output of 40,000,000 tons per year of lignite and 120,000,000 cubic meters per year of overburden from one pit will be completed.

Such a magnitude of operations, with their depth, lithology of rocks, and the fact that mining extends deep below the groundwater table, make it necessary to have the dewatering system ready in advance.

DEWATERING SYSTEMS DESIGN AND THE DESIGN REVISION

In Poland, the design of mine dewatering systems is done by specialized design and consulting companies. They are:

- The Central Design Office in Katowice, for underground mining of bituminous coal.
- The Cuprum in Wroclaw, for underground mining of ores.
- The Poltegor in Wroclaw, for all surface mines.

The large mine dewatering systems are designed in three phases:

(i) Feasibility studies are made for new mines. In these studies, estimate of expected groundwater inflow must be made and general ideas of multialternative technical solutions should be presented and compared from the financial and technical point of view. Also the outlines of the required hydrogeological investigation needed for a detail design should be proposed. These feasibility studies are submitted for revision and approval by the company that intends to invest in and develop the deposits.

(ii) Preliminary design should contain the general description of the entire dewatering system in one (maximum two) alternative. The inflow of groundwater and the size of the depression cone outside the mine should be calculated; the dewatering arrangements should be sited and selected and the technology of their construction detailed. The required equipment and installations should be listed as should the number and the specifications of the staff to be employed; the environmental impacts and control measures, therefore, have to be presented. In conclusion, the investment and operational costs, as well as the timetable of system construction, should be elaborated. The preliminary design must be approved by the Ministry that supervises the mining company or, in the case of a large operation, by the State Commission for Economical Planning. From the standpoint of environmental protection, the preliminary design of a dewatering system must also be approved by local authorities.

(iii) Technical designs are made for particular installations or units (i.e., draining wells, monitoring wells, pumping station, sedimentation pond, etc.); they should contain the detailed location of every element and the technology of its construction, which is used by the construction company. These designs must be approved by the mining company with participation of the construction company, if different.

The above designs are made on the basis of Geological Reports prepared by the geological company that does the field prospecting. These Geological Reports (also containing the resources assessment) must be approved by the National Geological Administration. For this approval, the design office's opinion, with a statement that the scope of investigation is sufficient for system design in the related phase, is required. Other data for dewatering system design includes the requirements of mining extraction design as well as the environmental authorities' requirements.

The most significant data are:

(i) Lithologic, tectonic and stratigraphic characteristics of the strata within the whole basin and in its surroundings.

(ii) Thickness and extent of aquifers.

(iii) Hydraulic contacts between particular aquifers and between aquifers and surface water (i.e., lakes and rivers).
(iv) Permeability and specific yields of aquifers.
(v) The requirements by mining technology, area, and depth of the groundwater table drawdown.
(vi) Time of drawdown required by mining operations.
(vii) Requirements regarding location, quantity, and quality of mine drainage discharge.

The data mentioned in (i) to (iv) should be estimated while making the hydrogeological prospectus and investigation and should be included in the officially approved Geological Report mentioned above. The data mentioned in (v) and (vi) must be provided by the extraction system designers and the data from (vii) should be given by local water and environmental authorities.

METHOD OF HYDROGEOLOGICAL AND HYDROLOGICAL CALCULATIONS

The goal of the calculations made for dewatering systems design is to obtain:

- Inflow of ground and precipitation water with time.
- Shape and time of depression cone development.
- Output of particular elements.
- Spacing between draining elements.
- Time needed to draw down the groundwater table.

Depending on the size of the dewatering system and the time of dewatering, the calculations, based on the assumption of steady or unsteady flow, are applied (4). In both the above cases, for small and simple systems, the analytical solutions of formula derived from classic Dupuit and Theiss equations are used. For large and complicated systems the modeling methods are used (4). Until the beginning of the 1970s, methods based on hydraulic (i.e., Hele-Shaw) and electrical (EHDA or pattern integrator) analogy were used. Recently the numerical methods have prevailed. These methods deal with Boussinesque equation solved on plane with a regular or irregular discreteness. For calculations, the finite element or finite difference method with iteration (i.e., Gauss-Seidel or Galerkin) are applied. The programs are written in Fortran 1900 language, and Polish third generation computers, ODRA 13 series, are used.

Depending on quality and credibility of input data (received mostly from hydrogeological investigations), the results show ± 10 to 20 percent differences compared with the actual results. For systems with 10 to 400 cubic meters per minute inflow, this could be assumed satisfactory.

Also quite good results can sometimes be obtained with the use of very simple calculations based on analogy to the existing systems proved under similar conditions.

DEWATERING METHODS AND ARRANGEMENTS

In underground mines the main methods of protection against uncontrolled inrush of groundwater are:

- Protective and safety pillars and shelves.
- Moving and sealing of surface waters.
- Sealing of workings.
- Construction of insulating benches.
- Drilling of horizontal drainage holes in advance of the face progress (to 100 meters long).
- Execution of drainage holes to drawdown the groundwater or reduce its pressure.
- Vacuum draining holes constructed where quicksand is found.
- Construction of sealed stoppings.

For continuous removal of water inflow, pumping stations, with 120 percent of reserve in pumps and water reservoirs to hold a 16-hour inflow, are constructed in the lower level of the mine.

Cost of dewatering provisions in underground mining is rather low; it is within 2 percent of total investment and operational costs.

In lignite surface mines, where the size and scope of dewatering systems is the largest, the following procedures are used:

(i) Drainage wells (Figure Nos. 7 and 8) are drilled from the surface and equipped with submersible pumps; the diameter of wells is 300 to 1,000 millimeters, and their depth is 50 to 350 meters. The output of these wells, depending on aquifer thickness and permeability, is 0.5 to 6.0 cubic meters per minute. In the well casing,

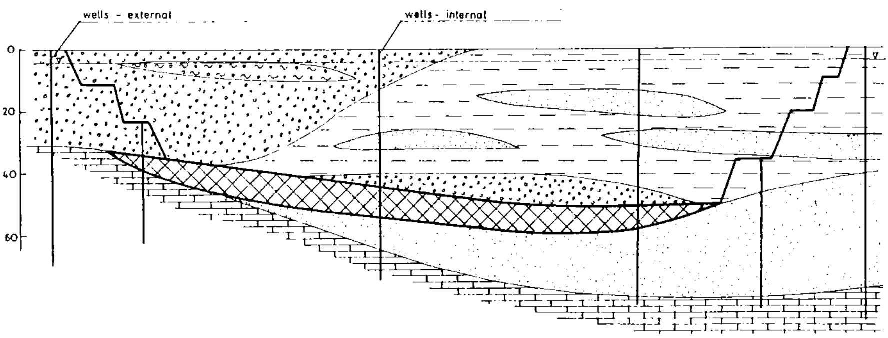


Fig.7. SCHEME OF DEWATERING SYSTEM OF ADAMOW SURFACE LIGNITE MINE.

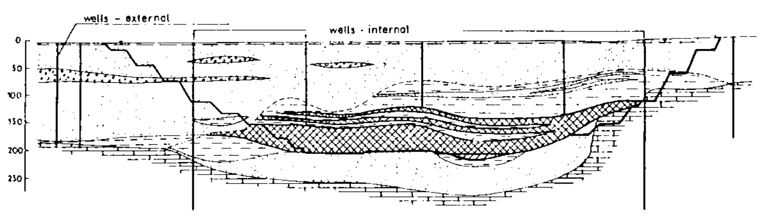


Fig.8. SCHEME OF DEWATERING SYSTEM OF BEŁCHATÓW SURFACE LIGNITE MINE.

the lower part (about 10 meters long) serves to keep the sand grains coming through, the filter section (which consists of perforated pipes wrapped with gauze and surrounded with gravel packing) and the upper pipe part, could be distinguished. The drainage wells are located around the mine and in internal galleries; the spacing between wells in galleries is in the 80- to 150-meter range, and the distance between galleries is 200 to 600 meters.

(ii) Underground drainage galleries are drifts in the lignite seam at about 200-meter spacing. The seam is accessible through the pits or declines. The drainage system for the overburden is the holes drilled from the surface. To drain the under seam aquifer, holes are drilled from galleries. Both types of drainage holes discharge groundwater to the galleries by natural forces. The water runs through the galleries to the underground pumping station and from there is pumped out onto the land surface. According to regulations, pumps must have 120 percent of reserve and must be fed with energy from two independent sources; water reservoirs must have enough volume to contain two hours inflow (Figure Nos. 9 and 10).

(iii) Impermeable diaphragms are constructed where the open pit cuts the very permeable layers which have contact with rivers or lakes; these screens are excavated with shovels or drilling equipment specially designed for excavations to 30 meters deep and 0.3 to 0.8 meter wide; the sealing medium is mostly a mixture of special cement and clays or chemical components.

(iv) Horizontal holes from the slopes as well as drainage holes which channel groundwater from upper to lower aquifers are used as supplementary procedures.

(v) Dewatering trenches are excavated within the open pits to catch rainwater and the remaining groundwater missed by the above procedures. The water flows through these trenches to pumping stations; the trenches on the permanent slopes are lined and on periodic slopes are made without a casing. The width of the bottom of the trenches is 0.6 to 1.0 meter, their slope inclination is 1:1.5 to 1:2.0; their depth is 1.0 to 2.0 meters and their longitudinal dipping is 1 to 2 meters per thousand.

(vi) Pumping stations are located in the lowest parts of open pits as stable or shiftable units, and, according to Polish regulations, must have 50 to 100 percent of reserve in pumps and reservoirs for 4-hour retention of

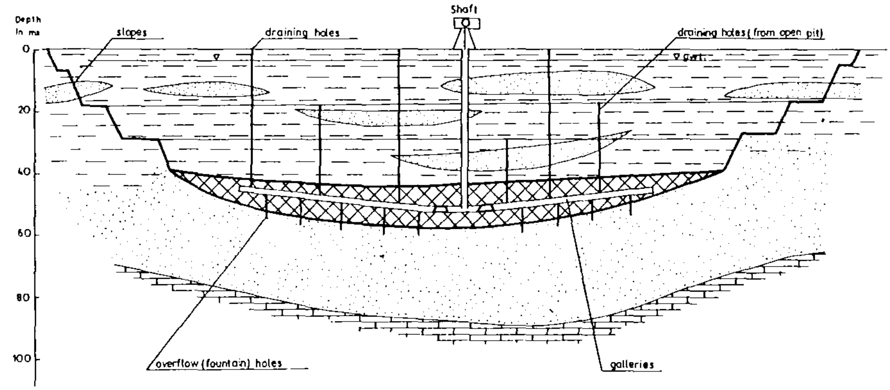


Fig.9. SCHEME OF DEWATERING SYSTEM OF KONIN SURFACE LIGNITE MINE.

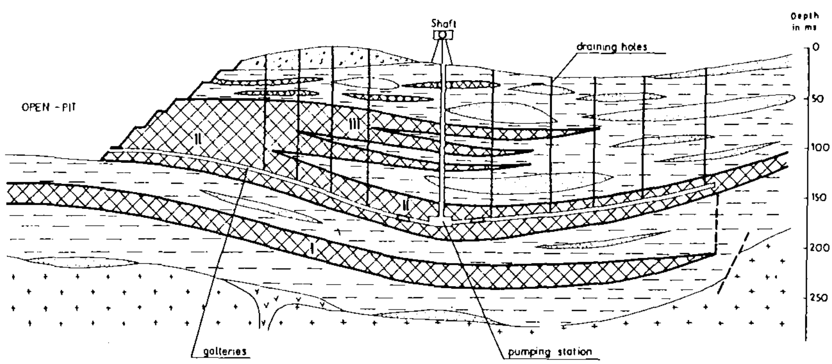


Fig.10. SCHEME OF DEWATERING SYSTEM OF TURÓW SURFACE LIGNITE MINE.

total inflow. The inflow is calculated as 24-hour amount with probability coefficient p = 10 percent. (Figure No. 11)

(vii) Sedimentation ponds are used to purify mine drainage from mineral and organic suspension, because this contains 100 to 1,000 ppm of suspended matter. In the sedimentation ponds of 1- to 3-day retention time, the reduction of suspended matter concentration is effected in a natural sedimentation process, down to 50 ppm. Recently, to improve the effect (below 30 ppm) and to reduce the size of sedimentation ponds in mines, with inflow of 50 to 200 cubic meters per minute, flocculents and also the grass filter process are being introduced.

In surface lignite mines, the combination of all or some of the above technical means is used. In surface sulphur mines, only wells and supplementary procedures are used. In stowing sand and clays surface mines only, the procedures described in items (v), (vi), and (vii) are used.

For the newly developed lignite mines, the dewatering systems begin operation one or two years before the heavy machines start to remove the overburden. During current operations the dewatering system advances the slopes of the open pit by about one year.

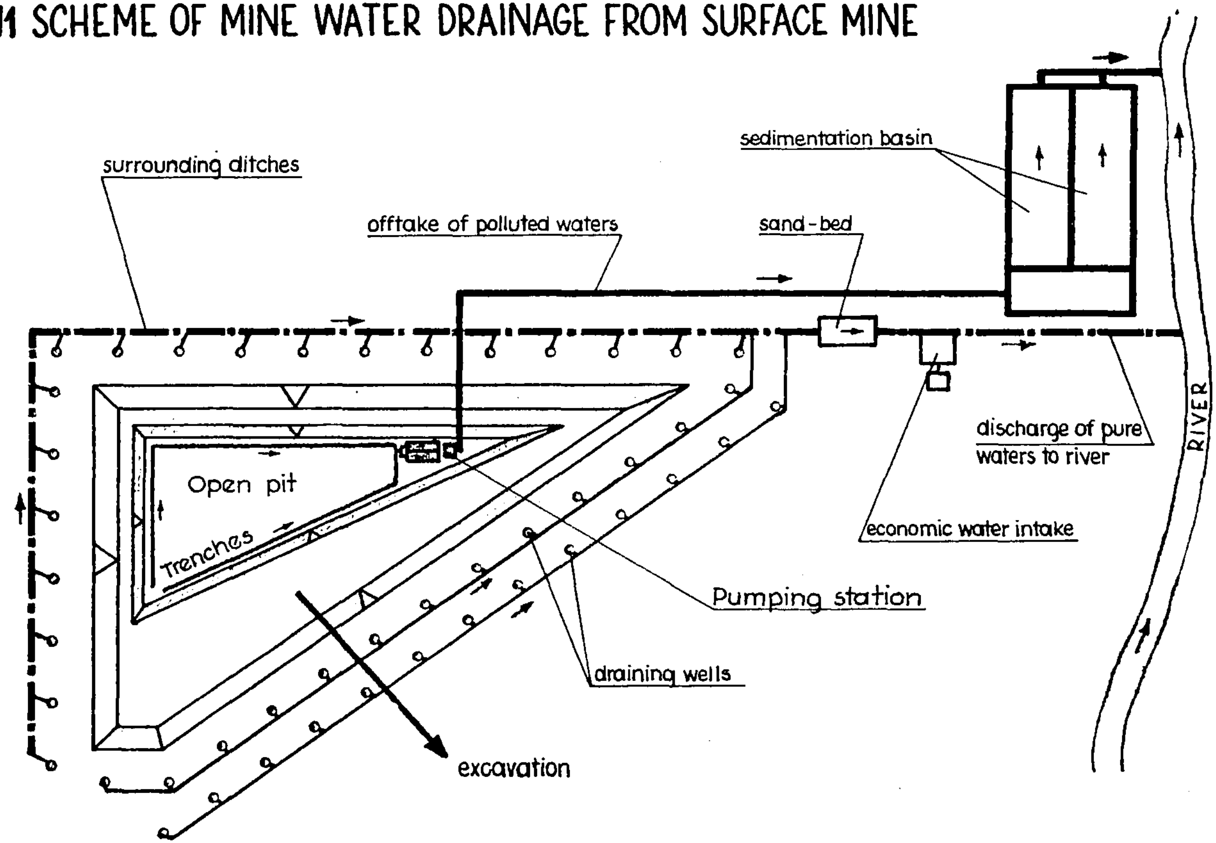
In surface mines of other useful minerals, such advance time is shorter.

In Poland, the cost of surface mine dewatering systems is a factor in about 10 to 25 percent of total investment and operational cost of lignite mines. In other surface mines, except sulphur, the percentage is much smaller.

CONCLUSIONS

1. In all mining operations, below the groundwater table, the proper design of dewatering systems is an indispensable condition of undisturbed work.
2. The proper design of mine dewatering systems is directly dependent on the sufficiency and correctness of hydrogeological recognition.
3. In the underground mines and in open pits dug in hard rock, the aim of a dewatering system is to protect people and mine workings against flooding.

Fig.11 SCHEME OF MINE WATER DRAINAGE FROM SURFACE MINE



4. In the surface mines operated in loose grounds (sands, clays, mud), the proper dewatering of overburden, of useful mineral, and underlying beds is an indispensable factor in keeping the slopes stable, as well as excavator output and safety.
5. The design of mine dewatering systems should take into consideration the wide scope of environmental protection requirements, especially the quantitative and qualitative protection of ground and surface water.

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